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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

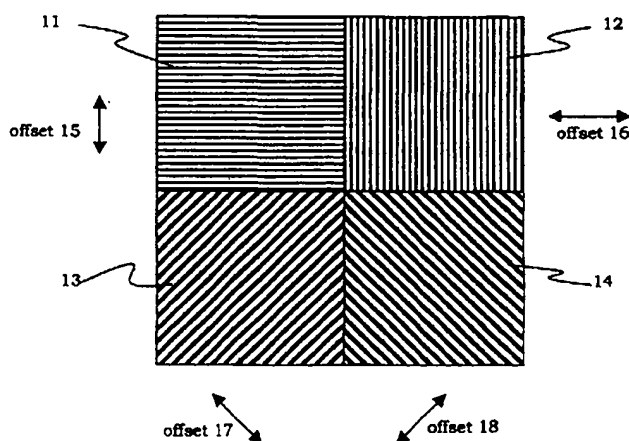
(19) World Intellectual Property Organization  
International Bureau(43) International Publication Date  
6 September 2002 (06.09.2002)

PCT

(10) International Publication Number  
**WO 02/069390 A2**

- (51) International Patent Classification<sup>7</sup>: **H01L 21/66** (74) Agents: **YIM, Peter, J.** et al.; Morrison & Foerster LLP, 425 Market Street, San Francisco, CA 94105-2482 (US).
- (21) International Application Number: PCT/US02/05648 (81) Designated States (national): JP, KR, SG.
- (22) International Filing Date: 25 February 2002 (25.02.2002) (84) Designated States (regional): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data: 09/794,686 27 February 2001 (27.02.2001) US
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- Published:**  
without international search report and to be republished upon receipt of that report
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: GRATING TEST PATTERNS AND METHODS FOR OVERLAY METROLOGY

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(57) **Abstract:** A metrology for determining bias or overlay error in lithographic processes. This metrology includes a set of diffraction test patterns, optical inspection techniques by using spectroscopic ellipsometer or reflectometer, a method of test pattern profile extraction. The invention uses a set of diffraction gratings (10) as the test patterns, and thin film metrology equipment, such as spectroscopic ellipsometer or spectroscopic reflectometer. The profiles of the test patterns in the two successive layers are analyzed. Overlay information are obtained after processing the profile data. In a first aspect of the invention, a line-on-line overlay grating test patterns structure is disclosed in which a second layer mask is placed in the center of a clear line in a first layer mask. In a second aspect of the invention, a line-on-line overlay grating test patterns structure is disclosed in which a second layer mask is placed in the center of a dark line in the first mask.

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## Grating Test Patterns and Methods for Overlay Metrology

### 5        Field of the Invention

The present invention relates generally to precision optical measurement of the two process layers on a semiconductor wafer, and more particularly to a set of diffraction grating test patterns that are used in combination with rigorous diffraction grating analysis.

### 10       Description of Related Art

Lithography continues to be the key enabler and driver for semiconductor industry. Metrology equipment and method for critical dimension (CD) and overlay control are the key elements of the lithography infrastructure. Overlay and CD control over large field sizes will continue to be a major concern for sub-100nm lithography.

15    Overlay requirements are among the most difficult technical challenges in lithography.

The main contributors to overlay error are the stage, alignment system and distortion signature. Errors can be broken down into stage motion or wafer alignment errors such as placement and rotation inaccuracies and field errors like errors on the reticle and in camera magnification. These errors are correctable. Pincushion or barrel  
20    distortions, third-order field errors, are not correctable. The overlay errors must be routinely characterized for a given exposure tool. Three fundamental components of overlay are the alignment target detection capability, the stage positioning accuracy and precision, and the difference in lens distortion between two tools used to expose overlaying process layers.

Technologies utilized for overlay measurement include electrical test, scanning electron microscope (SEM), and optical microscope. Coherence probe microscopy (CPM), by adding an interferometer to the microscope, enables phase-based measurements that can pick up subtle differences in index of refraction and topography.

5 Optical microscope technology has been the dominant measurement technique.

Overlay targets often are variations of box-in-a-box. The center of each box is calculated independently, and a difference between them is determined. Some metrology tools measure overlay error as a combination of linewidth measurements. To increase contrast, the boxes can be replaced with combinations of bars and frames, which add  
10 structure at the target's perimeter by providing two edges instead of one. A shortcoming is that there is no practical standard for overlay. Therefore, a true value for any particular overlay target is not known. Some fabs may periodically look at cross sections or make comparisons to electrical parameters, but this is time consuming and relegated to characterization environment, rather than in production.

15 Alignment target detection became a show-stopper for many exposure tools with the proliferation of CMP levels, where very planarized metal layers present considerable challenges to finding and measuring a target's position.

One conventional solution uses a box-in-box test pattern. The details of this conventional solution is described in a section, for example, entitled "Semiconductor  
20 Pattern Overlay" in the Handbook of Critical Dimensions Metrology and Process Control, SPIE, vol. CR52, 1994, pp. 160-188.

Several shortcomings of conventional solutions include, asymmetry of patterned line profile, aberrations in the illumination and imaging optics, individual test pattern image sampling, and for polished layers, the signal-to-noise (S/N) ratio in prior arts can be poor and affected by contrast variations in film thickness.

5           Accordingly, it is desirable to have a method and system for grating overlay patterns that are fast and flexible.

### SUMMARY OF THE INVENTION

The invention uses a set of diffraction gratings as the test patterns, and thin film metrology equipment, such as spectroscopic ellipsometer and spectroscopic reflectometer.

10   The profiles of the test patterns in the two successive layers are analyzed. Overlay information are obtained after processing the profile data. In a first aspect of the invention, a line-on-line overlay grating test patterns structure is disclosed in which a second layer mask is placed in the center of a clear line in a first layer mask. In a second aspect of the invention, a line-in-line overlay grating test patterns structure is disclosed in

15   which a second layer mask is placed in the center of a dark line in the first mask.

Advantageously, the present invention uses a spectroscopic ellipsometer or spectroscopic reflectometer without the necessity in requiring a highly precise focusing optical system. Moreover, the present invention provides overlay information of a test pattern which contains at least 30 repetitive structures. For example, based on one

20   measurement, the present invention provides an average overlay information over at least 30 samples. Furthermore, the present invention requires less precise wafer stage, so the metrology equipment is considerably cheap than those for prior arts.

Other structures and methods are disclosed in the detailed description below. This summary does not purport to define the invention. The invention is defined by the claims.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial diagram illustrating quad orientations of overlay patterned  
5 grating lines in accordance with the present invention.

FIGS. 2A-2E are process diagrams illustrating a line-on-line overlay patterned grating in accordance with the present invention.

FIGS. 3A-3D are process diagrams of various examples of adding one or more layers in a line-on-line overlay patterned grating in accordance with the present invention.

10 FIGS. 4A-4E are process diagrams illustrating a line-in-line overlay patterned grating in accordance with the present invention.

FIGS. 5A-5D are process diagrams of various examples of adding one or more layers in a line-on-line overlay patterned grating in accordance with the present invention.

FIG. 6 is a process diagram illustrating a first example of a line-in-line structure in  
15 accordance with the present invention.

FIGS. 7A-7B are graphical diagrams illustrating the overlay measurement of the line-in-line structure in FIG. 6 using an ellipsometry in accordance with the present invention.

FIG. 8 is a process diagram illustrating a second example of a line-in-line  
20 structure in accordance with the present invention.

FIGS. 9A-9B are graphical diagrams illustrating the overlay measurement of the line-in-line structure in FIG. 8 using an ellipsometry in accordance with the present invention.

FIG. 10 is a process diagram illustrating a first example of a line-on-line structure  
5 in accordance with the present invention.

FIGS. 11A-11B are graphical diagrams illustrating the overlay measurement of the line-on-line structure in FIG. 10 using an ellipsometry in accordance with the present invention.

FIG. 12 is a process diagram illustrating a second example of a line-on-line  
10 structure in accordance with the present invention.

FIGS. 13A-13B are graphical diagrams illustrating the overlay measurement of the line-on-line structure in FIG. 12 using an ellipsometry in accordance with the present invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)**

15 FIG. 1 is a pictorial diagram illustrating the quad orientation of overlay patterned gratings 10, with a grating A 11, a grating B 12, a grating C 13, and a grating 14. The orientation of the patterned grating lines in the present invention is placed at 0, 90, -45, and 45 degrees. The grating A 11 is orthogonal with the grating B 12, and the grating C 13 is orthogonal with the grating D 14.

20 In the grating A 11, the overlay test pattern lines extend horizontally, with the desirable offset that is detected in an arrow direction 15. In the grating B 12, the overlay test pattern line extends vertically, with the desirable offset that is detected in an arrow

direction 16. In the grating C 13, the overlay test pattern lines extends diagonally with a positive slope, with the desirable offset that is detected in an arrow direction 17. In the grating D 14, the overlay test pattern lines extend diagonally with a negative slope, with the desirable offset that is detected in an arrow direction 18. An orthogonal pair can provide overlay information in any orientation. Furthermore, an orthogonal pair can avoid loading/unloading of a wafer for different overlay orientation requirements.

A mask is a pattern tool which contains patterns that can be transferred to an entire wafer in one exposure. A mask is said to be a dark-field (or negative) tool, if the field (or background) areas are opaque, and to be a clear-field (or positive) tool is the field is transparent.

FIGS. 2A-2E are process diagrams illustrating a line-on-line overlay test structure. Here we use positive masks for the illustration. FIG. 2A shows a first layer mask 20, with clear lines 20a, 20c, 20e, and 20g, and dark lines 20b, 20d, and 20f. The dark lines 20b, 20d, and 20f are wider than the clear lines 20a, 20c, 20e, and 20g. FIG. 2B shows that the photoresist is patterned after the lithography development 21. Photoresist 21a, 21b, and 21c are patterned over the first layer mask 20. FIG. 2C shows that the material under photoresist is patterned after the etch process 22 (note that photoresist is removed). FIG. 2D shows the second layer mask 23, with clear lines 23a, 23c, 23e, and 23g, and dark lines 23b, 23d, and 23f. The clear lines 23a, 23c, 23e, and 23g are wider than the dark lines 23b, 23d, and 23f. FIG. 2E shows photoresist is patterned on the previous patterned layer 24. A  $d_1$  distance measures a gap from the left edge of the first dark line in the second mask to the left edge of the first dark line in the second mask; and a  $d_2$  distance

measures a gap from the right edge of the first dark line in the second mask to the right edge of the first dark line in the first mask.

There can be some material layers between the second lithography process and the first etch process. For example, FIGS. 3A-3D are process diagrams of various examples of adding one or more layers in a line-on-line overlay patterned grating. FIG. 3A shows a general structural diagram 30 with a first etch process 30a and the second lithography process 30b. In a first type of structural diagram 31 in FIG. 3B, a material layer 31a is inserted between the first etch process 30a and the second lithography process 30b. In a second type of structural diagram 32 in FIG. 3C, a material layer 32a is placed between the first etch process 30a and the second lithography process 30b. In a third type of structural diagram 33 in FIG. 3D, two material layers 33a and 33b are placed between the first etch process 30a and the second lithography process 30b.

FIGS. 4A-4E are process diagrams illustrating a line-in-line overlay test structure. Here we use positive masks for the illustration. FIG. 4A shows a first layer mask 40, with clear lines 40a, 40c, 40e, and 40g, and dark lines 40b, 40d, and 40f. The dark lines 40b, 40d, and 40f are narrower than the clear lines 40a, 40c, 40e, and 40g. FIG. 4B shows that the photoresist is patterned after the lithography development 41. Photoresist 41a, 41b, and 41c are patterned over the first layer mask 40. FIG. 4C shows that the material under photoresist is patterned after the etch process 42 (note that photoresist is removed). FIG. 2D shows the second layer mask 43, with dark lines 43a, 43c, 43e, and 43g, and clear lines 43b, 43d, and 43f. The dark lines 43a, 43c, 43e, and 43g are wider than the clear lines 43b, 43d, and 43f. FIG. 4E shows photoresist is patterned on the



previous patterned layer 44. A  $X_1$  45 distance measures a gap from the left edge of the first clear line in the second mask to the left edge of the first clear line in the first mask, and a  $X_2$  46 distance measuring a gap from the right edge of the first clear line in the second mask to the right edge of the first clear line in the first mask.

5        There can be some material layers between the second lithography process and the first etch process. For example, Figure 5A-5D are process diagrams of various examples of adding one or more layers in a line-in-line overlay patterned grating. FIG. 5A shows a general structural diagram 50 with a first etch process 50a and the second lithography process 50b. In a first type of structural diagram 51 in FIG. 5B, a material layer 51a is  
10        inserted between the first etch process 50a and the second lithography process 50b. In a second type of structural diagram 52 in FIG. 5C, a material layer 52a is placed between the first etch process 50a and the second lithography process 50b. In a third type of structural diagram 53 in FIG. 5D, two material layers 53a and 53b are placed between the first etch process 50a and the second lithography process 50b.

15        The advantages provided by the orientation of patterned grating lines 10 are as follows. First, for spectroscopic reflectometry, there is not need to change the wafer. Overlay results obtained at different orientation angle can help to reduce random error. Secondly, for spectroscopic ellipsometry, the information from -45 and +45 degree provide complete minimum requirement for a overlay metrology purpose, with out the  
20        requirement to reload wafer. And the information from 0 or 90 degree provides the most accurate overlay data.

At each orientation, the present invention has two test patterns, which are called “line-in-line” and “line-on-line” test patterns. The theoretical studies are shown in following sections.

A complete 2- and 3-dimensional periodic profiles can be measured using phase  
5 and/or intensity information from optical techniques such as spectroscopic ellipsometry and reflectometry, as described in a co-pending patent application entitled “Optical Profilometry for 2-D and 3-D Sub-Micron Periodic Features With Three or More Material in the Periodic Layers”, assigned to the same assignee, and accorded an application number of \_\_\_\_\_, which is incorporated herein by  
10 reference in its entirety.

Simulations are performed to support the concepts described above. In all of the examples, it is shown that a 10nm overlay error can be detected with the presented invention. FIG. 6 is a process diagram illustrating a first example of a line-in-line structure 60. A resist 61 is placed in between a PolySi 62 and a PolySi 63. The pitch is  
15 600 nm from the left edge of the PolySi 62 to the left edge of the PolySi 63. If  $x_1 = 150$ , and  $x_2 = 150$ , then the resist 61 would be positioned in the center between the PolySi 62 and the PolySi 63. If the resist 61 moves 5 nm to the left, then  $x_1 = 145$ , and  $x_2 = 155$ . Or, if the resist 61 moves 5 nm to the right, then, then  $x_1 = 155$ , and  $x_2 = 145$ . FIGS. 7A-7B are graphical diagrams illustrating the overly measurement of the line-in-line structure  
20 in FIG. 6 using an ellipsometry.

FIG. 8 is a process diagram illustrating a second example of a line-in-line structure 80. In this example, before placing the resist 61, dielectric layers 81 and 82 are

deposited in between the PolySi 62, and the PolySi 63, followed by CMP (chemical mechanical polishing) planarization. Although edges for the PolySi 62 and the PolySi 63, are not longer detectable due to the fill-in of dielectric layers 81 and 82, the present invention can still detect the overlay since it is not dependent on detection of edges.

5 FIGS. 9A-9B are graphical diagrams illustrating the overlay measurement of the line-in-line structure in FIG. 8 using an ellipsometry.

FIG. 10 is a process diagram illustrating a first example of a line-on-line structure 100., with distance  $d_1$  101 and  $d_2$  102. FIGS. 11A-11B are graphical diagrams illustrating the overlay measurement of the line-on-line structure in FIG. 10 using an ellipsometry in  
10 accordance with the present invention.

FIG. 12 is a process diagram illustrating a second example of a line-on-line structure 120, with dielectric layers 121 and 122. FIGS. 13A-13B are graphical diagrams illustrating the overlay measurement of the line-on-line structure in FIG. 12 using an ellipsometry in accordance with the present invention.

15 The line-in-line and line-on-line overlay measurements can be applied to single wavelength variable incident angle optical metrology equipment. Additionally, the line-in-line and line-on-line overlay measurements can be applied to any combination of single wavelength variable incident angle optical metrology equipment and multiple wavelength fixed incident angle  
20 optical metrology equipment. Furthermore, the line-in-line and line-on-line overlay measurements can be applied to multiple wavelength multiple incident angle optical metrology equipment.

The above embodiments are only illustrative of the principles of this invention and are not intended to limit the invention to the particular embodiments described. Accordingly, various modifications, adaptations, and combinations of various features of the described embodiments can be practiced without departing from the scope of the  
5 invention as set forth in the appended claims.

CLAIMS

## WE CLAIM:

1. A line-on-line structure, comprising:  
a first mask having a plurality of dark lines and a plurality of clear lines,  
5 each dark line being placed adjacent to clear lines; and  
a second mask having a plurality of dark lines and a plurality of clear lines,  
each dark line in the second mask being placed in the center of a dark line in the first  
mask.
2. The line-on-line structure of Claim 1, when using a positive resist, the  
10 dark lines in the first mask being wider than the clear lines in the first mask.
3. The line-on-line structure of Claim 1, when using a negative resist, the  
dark lines in the first mask being narrower than the clear lines in the first mask.
4. The line-on-line structure of Claim 1, wherein the plurality of clear lines in  
the first mask are identical or substantially identical to one another, and wherein the  
15 plurality of the dark lines in the first mask are identical or substantially identical to one  
another, thereby the combination of clear lines and dark lines in the first mask producing  
a repetitive pattern on the first mask.
5. The line-on-line structure of Claim 1, wherein the plurality of dark lines in  
the first mask being wider than the plurality dark lines in the second mask.

6. The line-on-line structure of Claim 1, wherein the plurality of clear lines in the first mask being narrower than the plurality of clear lines in the second mask.

7. The line-on-line structure of Claim 1, wherein a first dark line in the plurality of dark lines in the second mask having a left edge and a right edge, and wherein  
5 a first dark line in the plurality of dark lines in the first mask having a left edge and a right edge.

8. The line-in-line structure of Claim 7, further comprising  
a  $d_1$  distance measuring a gap from the left edge of the first dark line in the second mask to the left edge of the first dark line in the second mask; and  
10 a  $d_2$  distance measuring a gap from the right edge of the first dark line in the second mask to the right edge of the first dark line in the first mask.

9. The line-on-line structure of Claim 8, wherein the first dark line in the second mask is in the center of the first dark line in the first mask if  $d_1 = d_2$ .

10. The line-on-line structure of Claim 8, wherein the first dark line in the  
15 second mask shifts to the right of the first dark line in the first mask if  $d_1$  minus  $d_2$  produces a positive number.

11. The line-on-line structure of Claim 8, wherein the first dark line in the second mask is shifts to the left of the first dark line in the first mask if  $d_1$  minus  $d_2$  produces a negative number.

20 12. A line-in-line structure, comprising:

a first mask having a plurality of dark lines and a plurality of clear lines,  
each dark line being placed adjacent to clear lines; and

a second mask having a plurality of dark lines and a plurality of clear lines,  
each clear line in the second mask being placed in the center of a clear line in the first  
5 mask.

13. The line-in-line structure of Claim 12, when using a positive resist, the  
plurality of clear lines in the first mask being wider than the plurality of dark lines in the  
first mask.

10 14. The line-in-line structure of Claim 12, when using a negative resist, the  
plurality of clear lines in the first mask being narrower than the plurality of clear lines in  
the first mask.

15 15. The line-in-line structure of Claim 12, wherein the plurality of clear lines  
in the first mask are identical or substantially identical to one another, and wherein the  
dark lines in the first mask are identical or substantially identical to one another, thereby  
the combination of clear lines and dark lines in the first mask producing a repetitive  
pattern on the first mask.

16. The line-in-line structure of Claim 12, wherein the plurality of dark lines  
in the first mask being narrower than the plurality dark lines of the second masks.

17. The line-in-line structure of Claim 12, wherein the plurality of clear lines in the first mask being wider than the plurality of clear lines in the second masks.

18. The line-in-line structure of Claim 12, wherein a first clear line in the plurality of clear lines in the second mask having a left edge and a right edge, and  
5 wherein a first clear line in the plurality of clear lines in the first mask having a left edge and a right edge.

19. The line-in-line structure of Claim 18, further comprising  
a  $X_1$  distance measuring a gap from the left edge of the first clear line in the second mask to the left edge of the first clear line in the first mask; and  
10 a  $X_2$  distance measuring a gap from the right edge of the first clear line in the second mask to the right edge of the first clear line in the first mask.

20. The line-in-line structure of Claim 18, wherein the first clear line in the second mask is in the center of the first clear line in the first mask if  $X_1 = X_2$ .

21. The line-in-line structure of Claim 18, wherein the first clear line in the  
15 second mask is shifts to the right of the first clear line in the first mask if  $X_1$  minus  $X_2$  produces a positive number.

22. The line-in-line structure of Claim 18, wherein the first clear line in the second mask is shifts to the right of the first clear line in the first mask if  $X_1$  minus  $X_2$  produces a positive number.

20 23. A method for multi-orientation of orthogonal pairs, comprising:



placing a grating; and  
shining a light on the grating wherein the light is not perpendicular to the  
orientation of the grating.

24. The method for multi-orientation of orthogonal pairs of Claim 23, wherein  
5 the orientation of the grating forms a positive slope.

25. The method for multi-orientation of orthogonal pairs of Claim 23, wherein  
the orientation of the grating forms a negative slope.

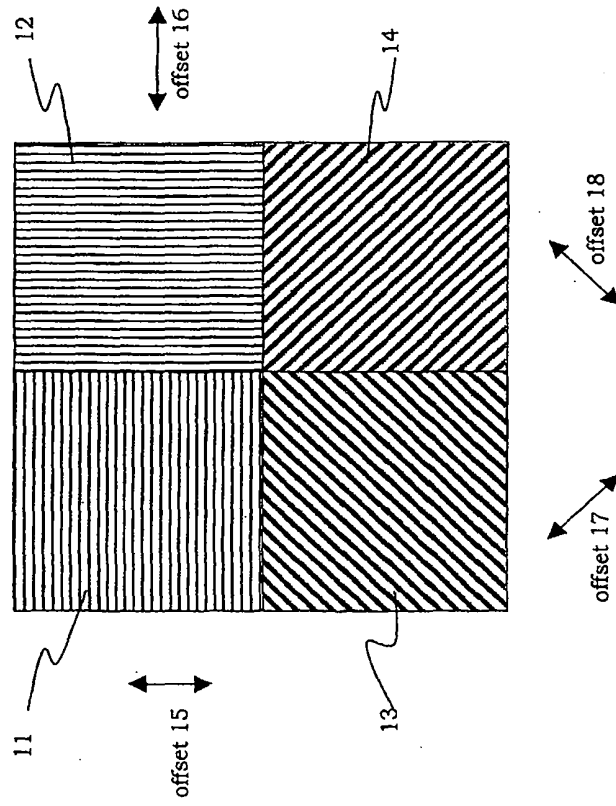
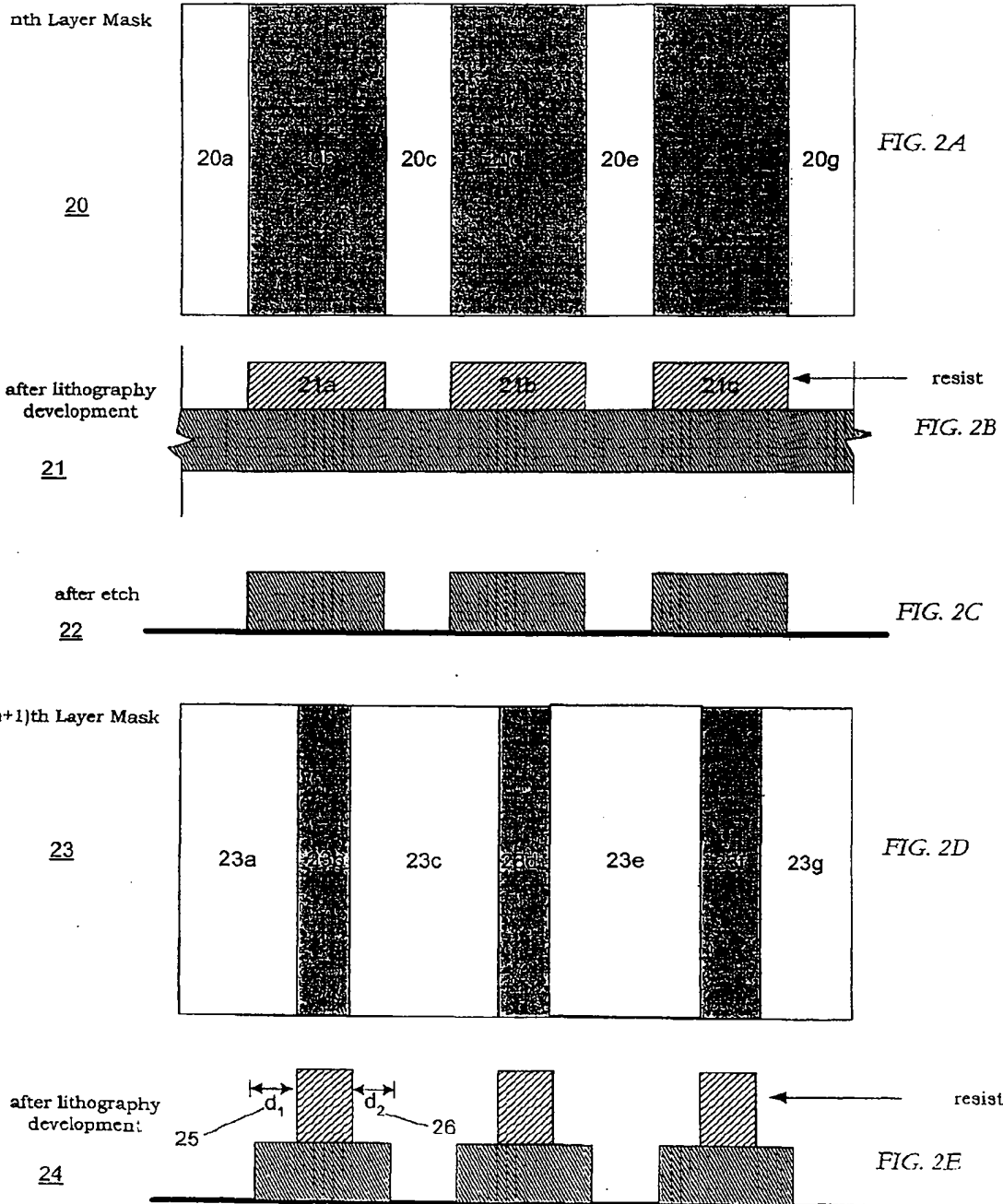


FIGURE 1

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# Line - on - Line



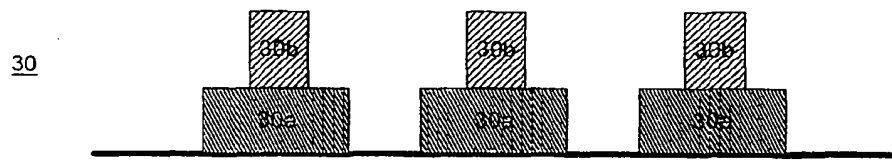


FIG. 3A

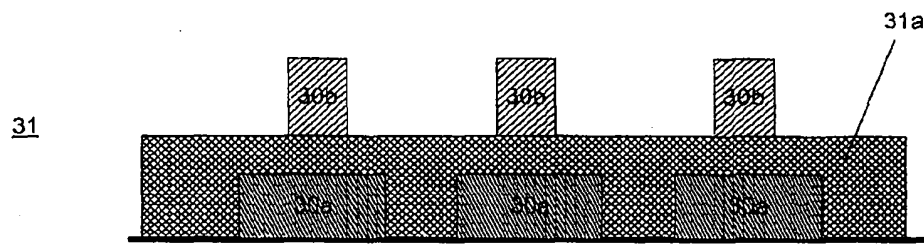


FIG. 3B

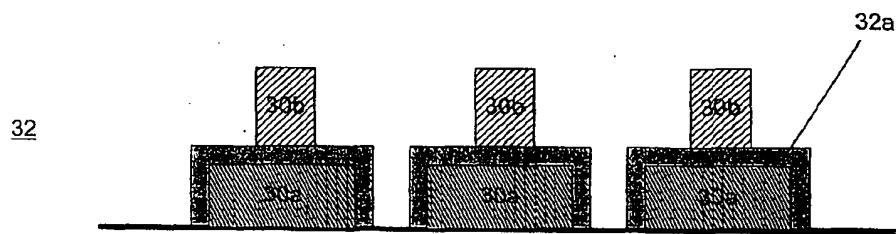


FIG. 3C

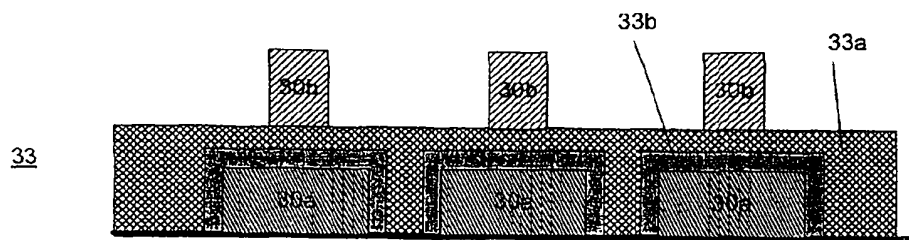
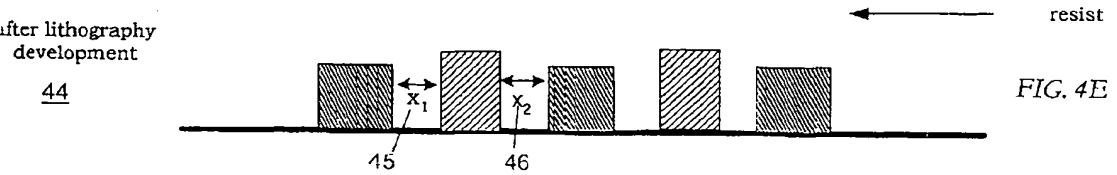
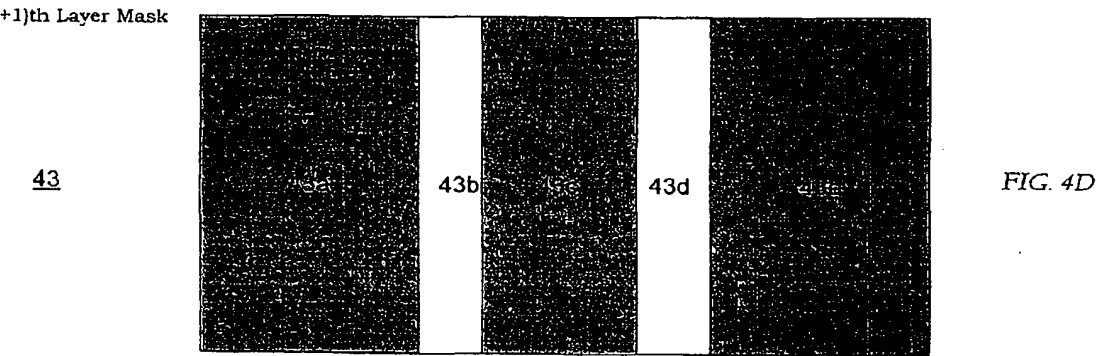
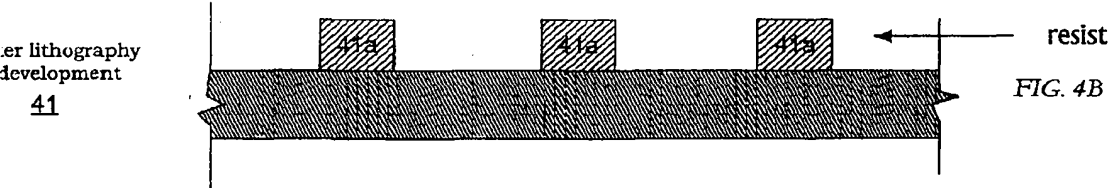
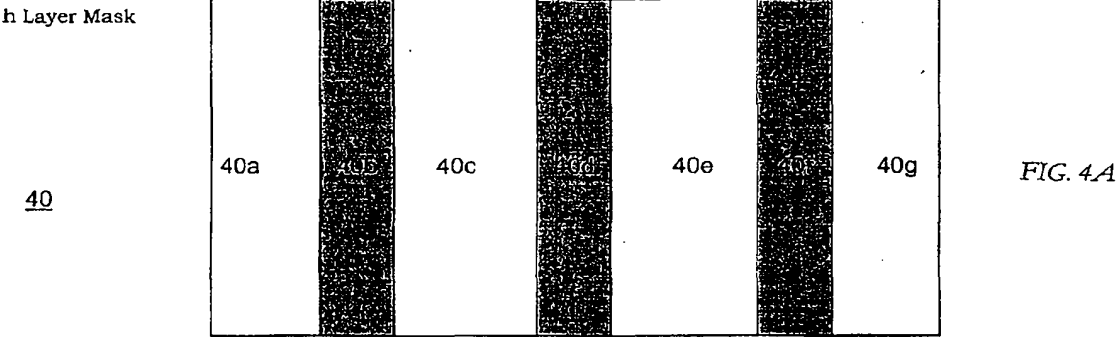
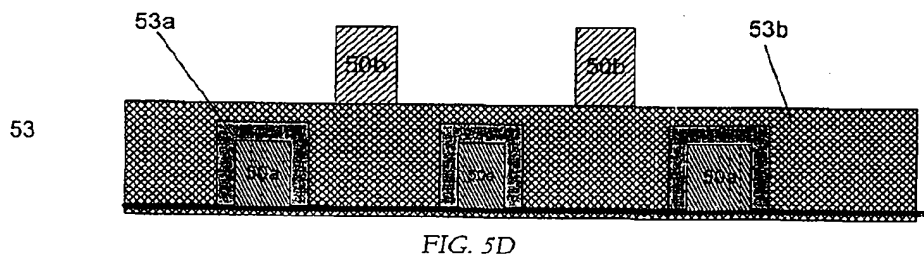
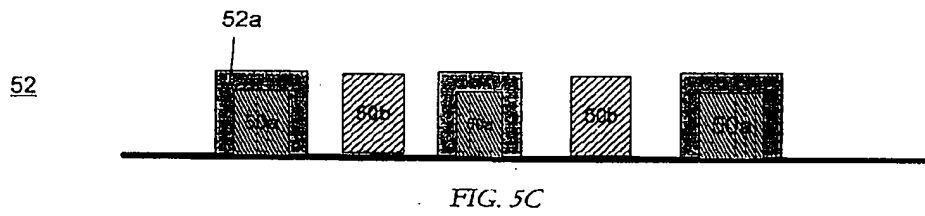
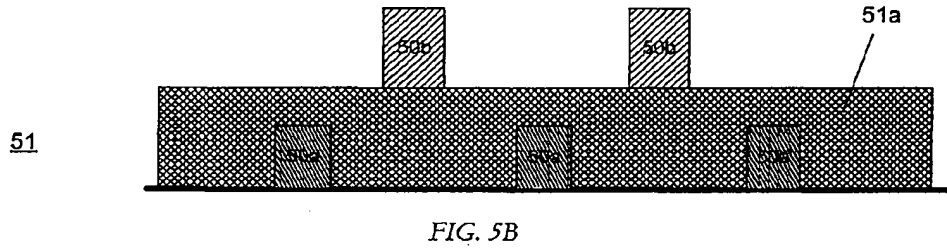
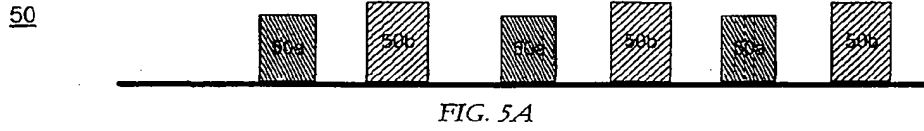


FIG. 3D

Line - in - Line





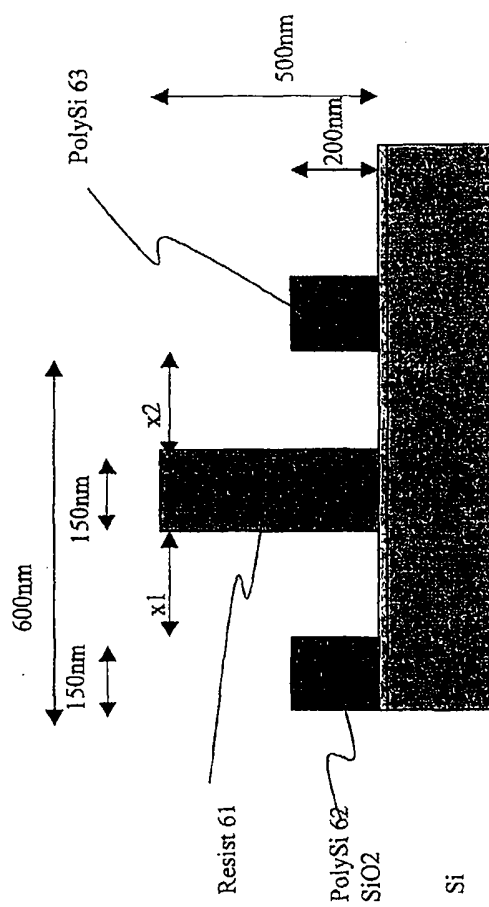


FIGURE 6

60

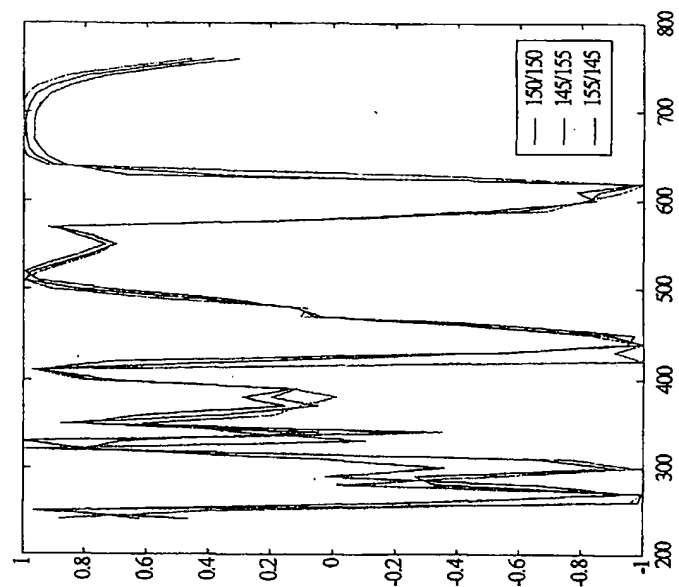


FIG. 7A

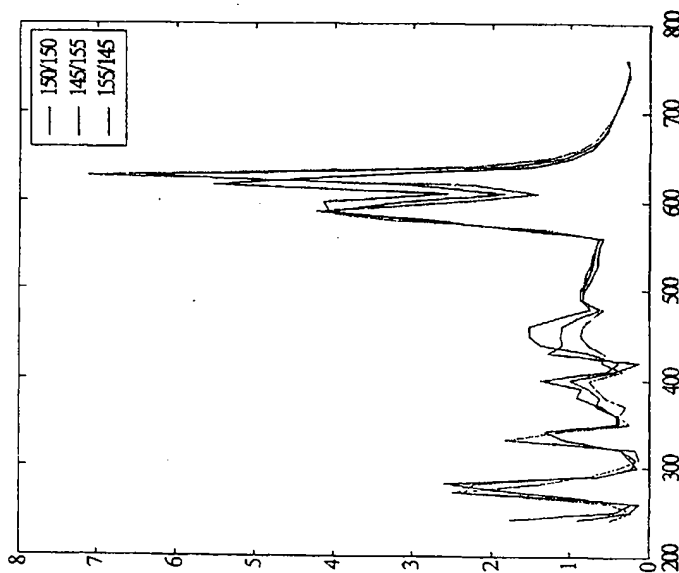


FIG. 7B



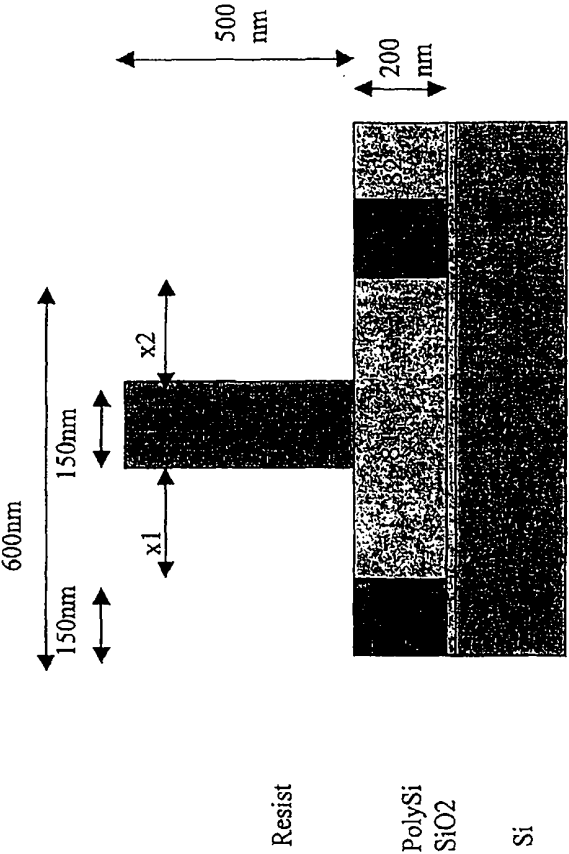


FIGURE 8

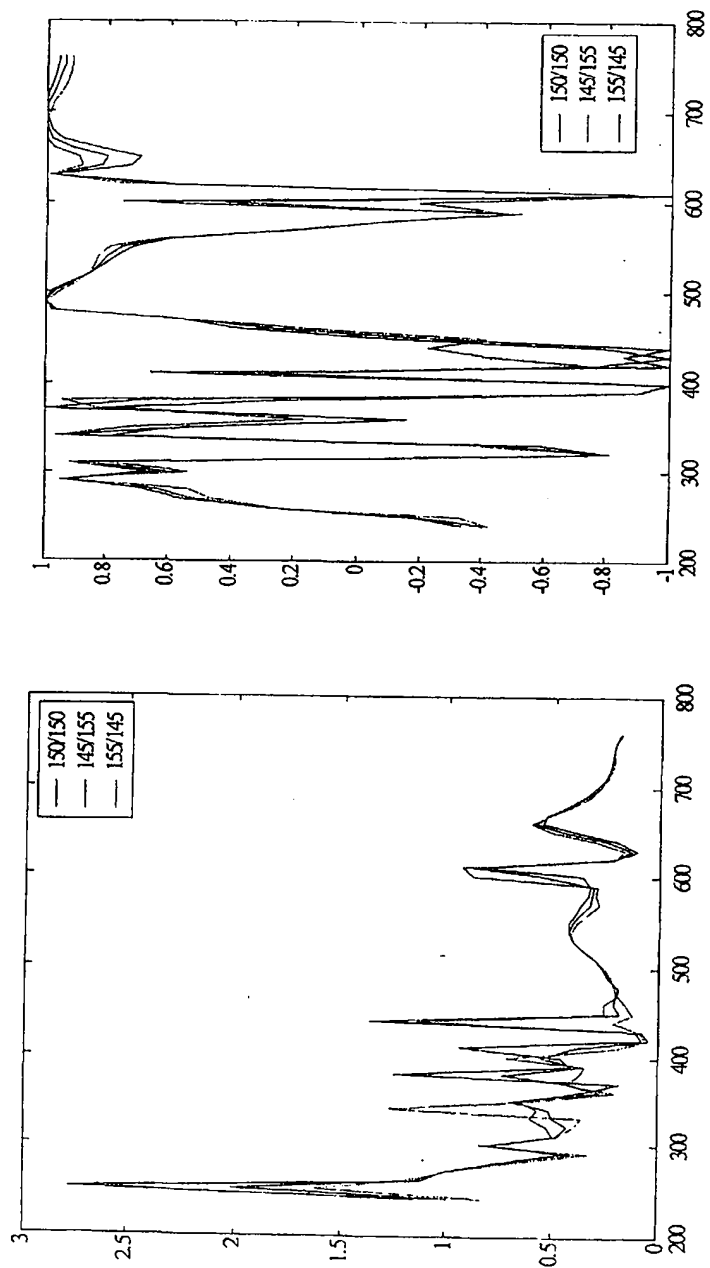


FIG. 9B

FIG. 9A

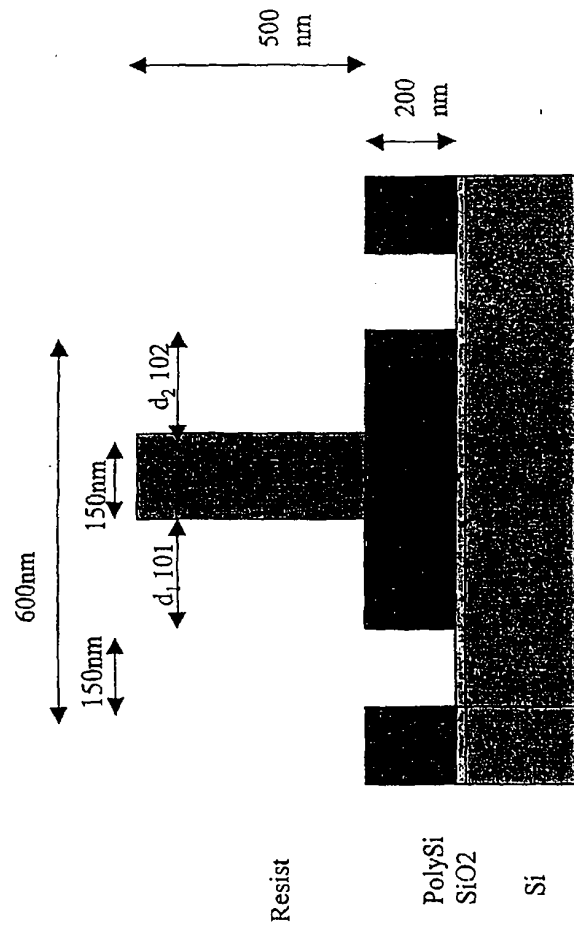


FIGURE 10

100

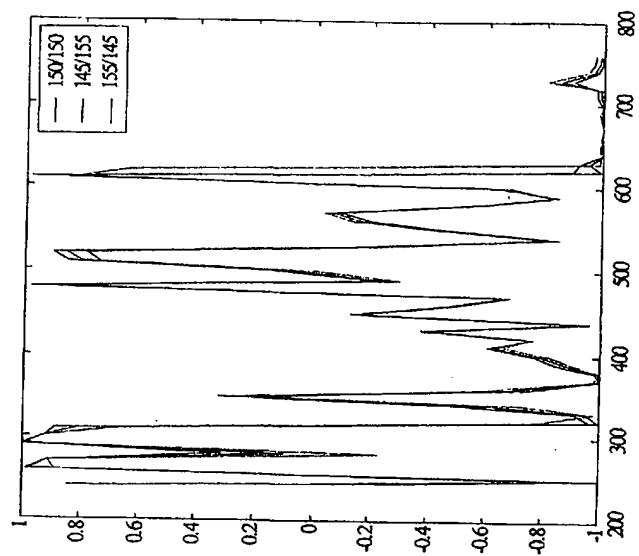


FIG. 11B

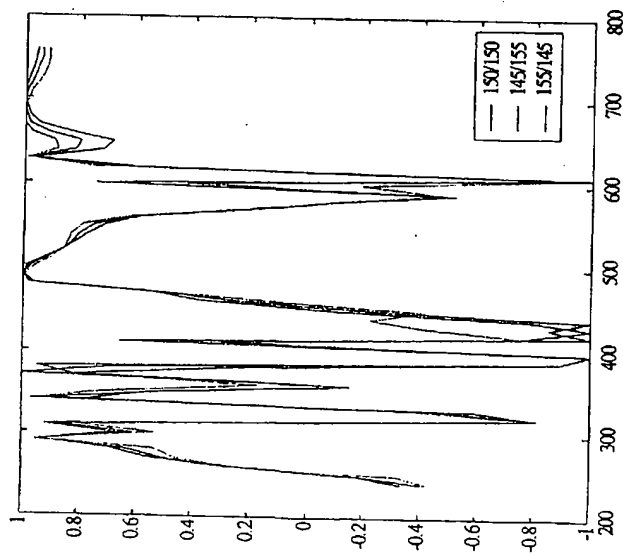


FIG. 11A

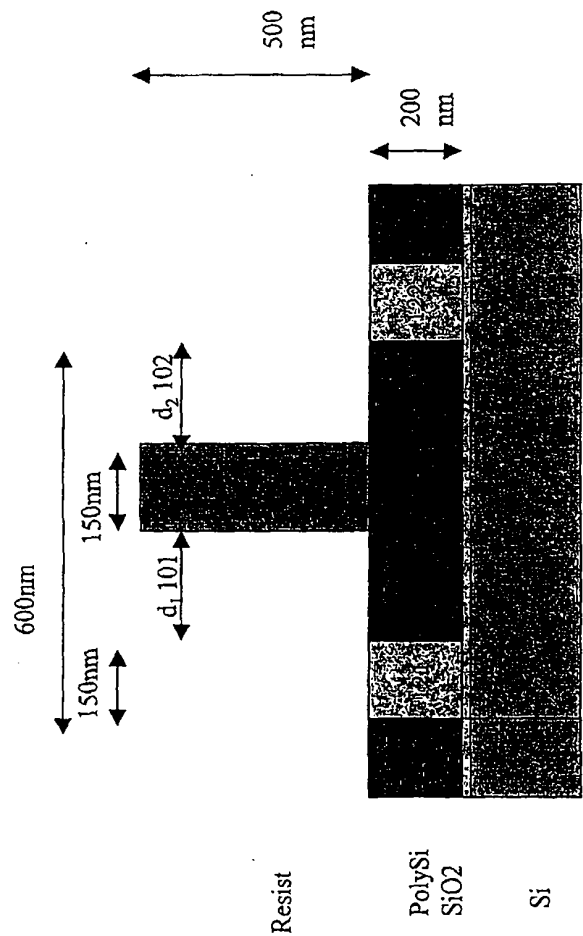


FIGURE 12

120

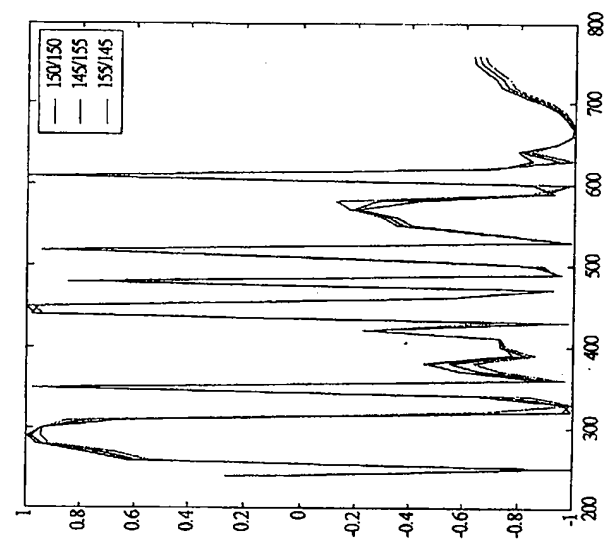


FIG. 13B

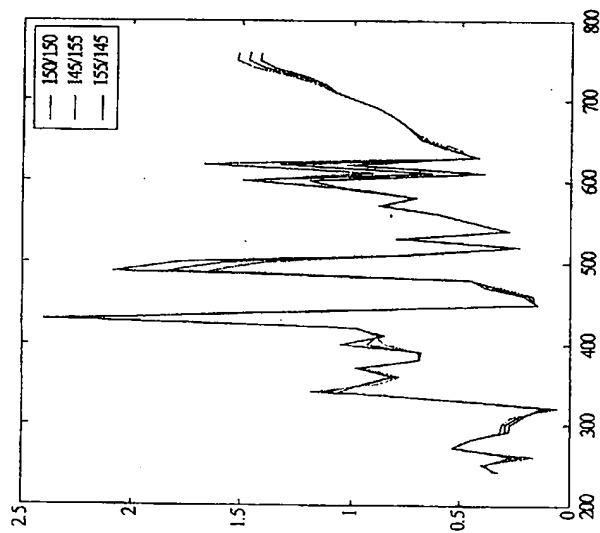


FIG. 13A